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A New Conical Band-Reject UWB Antenna with Uniform Rejection and Stable Omnidirectional Behavior

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Abstract—This paper introduces a new volumetric conical notch-band antenna. Structure of this antenna is in contrast with planar and printed band rejection antennas currently existing in almost all of the literatures. The radiation pattern of the proposed antenna is symmetrical and stable against frequency variation, while planar and printed antenna types suffer from high variation of their radiation pattern with frequency, and consequently asymmetric and unstable omnidirectional behavior. The frequency band of the antenna is notched with two slots implemented on the antenna structure. Uniform various frequency band rejections are achieved by changing the slots dimensions and position. Both measured and simulation results of manufactured antenna show the frequency bandwidth of the antenna is from 3 to 4.9 GHz and from 6.2 to 11 GHz with reflection coefficient less than −10 dB. Moreover, the antenna notches the frequency band from 4.9 to 6.2 GHz with nearly uniform reflection coefficient level of approximately −3 dB. Stable radiation pattern and proper range of frequency band rejection make the designed antenna an appropriate candidate for the use in UWB and indoor communication systems.

1. INTRODUCTION

The Federal Communication Commission (FCC) authorized the frequency bandwidth from 3.1 to 10.6 GHz with effective isotropic radiation power (EIRP) less than −41.3 dBm/MHz for commercial use in ultra wide band (UWB) systems [1]. Thereafter, the UWB system has been one of the best choices for high rate transmission of data. In addition, the UWB technology has been used in radars and RFID systems. Low radiation power and its subsequent long battery life as well as small size transmitter and receiver are major characteristics of UWB systems. IEEE 802.11a and HIPER LAN/2 standards allocate the frequency bandwidth from 5.15 to 5.825 GHz and from 5.15 to 5.725 GHz, respectively, for wireless communication systems [2, 3]. These frequency bands interfere with that of UWB systems. To reduce this interference, notch-band antennas may be used with the idea of rejecting the common frequency band. Moreover, the use of notch-band antennas in the UWB systems eliminates the need to use filter and therefore, reduces the complexity and size of the system.

Several methods have been used to disturb the surface current of the antenna in order to drop the radiation in a favorable range of frequency bandwidth. One of them is etching slots or slits on the radiating patch [4–8]. Other methods are implementation of stubs, parasitic elements, and compact resonance patches, which unfavorably increase the size of antenna [9, 10].

Low antenna gain, high level of the reflection coefficient, as well as high tunability of the notched frequency bandwidth, are important characteristics of the properly designed notch-band antenna; however, generally the latter property is difficultly achieved in design.

Various kinds of antennas with notched frequency band have been previously introduced. The most well-known one is the slot planar monopole antenna which has attracted many designers. Wide impedance bandwidth and easy implementation of slot planar monopole antenna have made it one of

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the best choices for UWB systems [11–18]. However, planar monopole antennas suffer from drawbacks; the radiation pattern loses its symmetry in high frequencies, and intensely varies with frequency which increases signal distortion.

In order to overcome the mentioned drawbacks of planar monopole antenna, Hu et al. proposed a new conical monopole antenna that notches a specific frequency band with C-shaped slots [19, 20]. This antenna unfavorably rejects some portion of the frequency band allocated to UWB due to its wide notched frequency band. In other words, the proposed antenna has high reflection coefficient level in the UWB frequencies lower than the frequencies used by HIPERLAN/2 and IEEE.802.11a systems.

This paper aims to introduce a new notched band antenna with wide frequency band as well as symmetrical and nearly constant H-plane radiation patterns in various frequencies. The proposed antenna rejects the favorable frequency band with steep upward and downward slopes at the beginning and end of that. In addition, it operates nearly uniform across the rejection frequency bandwidth. Small size, simple structure, and high power handling capability are the other prominent features that make the current antenna suitable for indoor communication systems compared with previously designed antennas.

2. SINGLE SLOT CONICAL MONOPOLE ANTENNA

The band-reject antenna proposed here has a conical shape as shown in Fig. 1. The frequency range of operation of monopole conical antennas is wide; however, to operate the antenna in the frequency band of UWB systems, essential design parameters should be properly determined. The antenna length and diameters and its distance from the ground are among these design parameters. The desired frequency bandwidth of the current antenna is from 3 to 11 GHz. The values for the antenna design parameters have been adapted from (1), [21] and are listed in Table 1.

$$f_c = \left(f_{\text{upper}} + f_{\text{lower}}\right)/2, \quad L_0 \cong 0.7\lambda_c, \quad D_U = 0.6\lambda_c \tag{1}$$

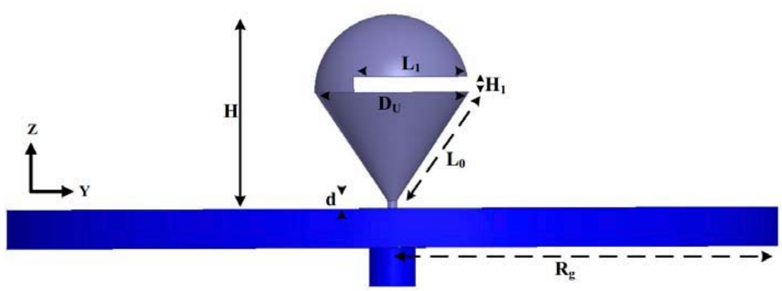


Figure 1. Designed single slot conical antenna.

Table 1. Dimensions of the proposed single slot conical antenna.

Symbol	Description	Length
H	Antenna length	25 mm
D_U	Upper diameter	20 mm
D_L	Lower diameter	1.3 mm
d	Distance from the ground	0.25 mm
L_0	Slant length of antenna	30 mm
R_g	Ground radius	50 mm
L_1	Slot Length	15 mm
H_1	Slot opening	2 mm

where, f_c is the center frequency of antenna bandwidth, D_U the antenna's upper diameter, and L_0 the slant length of antenna. In order to design a conical antenna covering UWB frequency range, the design frequency is assigned to center frequency of the UWB bandwidth, 7 GHz. Based on (1) and wavelength of the design frequency, the antenna upper diameter and the antenna slant length are determined about 20 mm and 30 mm respectively. The lower diameter of the antenna is specified as inner conductor diameter of SMA connector, 1.3 mm.

The frequency ranges from 5.15 to 5.35 GHz and 5.725 to 5.825 GHz have been assigned to IEEE 802.11a standard. The ranges 5.15 to 5.35 GHz and 5.47 to 5.725 GHz have been allocated to HIPERLAN/2 standard as well. The UWB antennas should eliminate these frequency ranges in order to reduce the interference of UWB communication system with systems using the above standards. To this end, an implemented slot in antenna structure contributes to reject a favorable frequency band. The slot on the antenna structure can be considered as a resonance structure with length (L_s) equal to quarter-wavelength at center frequency of notched frequency band. This slot prevents the antenna radiation in its resonance frequencies by distortion of surface current of antenna [22]. The slot length, (L_s), is determined as (2).

$$L_s = c/\left(4 * f_{C,\text{notch}}\right) \tag{2}$$

where $f_{C,\text{notch}}$ is center frequency of the desired notched frequency band.

Design parameters for the proposed antenna and its slot are shown in Fig. 1. The slant height, slot length and diameter of the larger base of the cone are denoted by L_0, L_1, and D_U, respectively. The length of designed slot (L_1) is determined identical to L_s calculated by (2). Therefore, various frequencies can be rejected by changing the slot length (L_1). For several values of L_1, the antenna has been simulated with High Frequency Structure Simulator (HFSS) [23] software package, and the obtained results are shown in Fig. 2. It can be seen that the notched frequency increases with the decrease of the slot length and vice versa. Therefore, the antenna is able to reject any desired frequency band with suitable slot length and position.

According to IEEE 802.11a and HIPERLAN/2 standards, the notched frequency range is assumed to be from 5 to 6 GHz. To obtain a uniform rejection in the notched frequency band, 5 GHz and 6 GHz are chosen as the notch frequencies to determine the length of first slot (L_1) and second slot (L_2), respectively. Therefore, based on (2) and $f_c = 5\,\text{GHz}$ the length of first slot (L_1) is chosen approximately equal to 15 mm.

The reduction of other systems interference is directly proportional to the level of rejection which is an essential parameter in UWB band-notched antennas. The slot opening is another design parameter that has minimal effect on the antenna reflection coefficient in notched frequency band. The variations of the reflection coefficient versus the slot opening (H_1) are illustrated in Fig. 3, where the maximum reflection coefficient is obtained with the slot opening of about 2 mm. As shown in Fig. 3, the variation of reflection coefficient versus slot opening is not significant.

The measured reflection coefficient of the manufactured antenna with $L_1 = 15\,\text{mm}$, the slot opening of about 2 mm, and its simulated results obtained with HFSS software are shown in Fig. 4. It shows that the reflection coefficient in the frequency band from 4.9 to 5.8 GHz is greater than $-10\,\text{dB}$, and the greatest value for it, about $-5\,\text{dB}$, takes place at the 5 GHz. Moreover, the measured and simulated VSWR versus frequency is shown in Fig. 5.

Low and high variation of group delays, respectively, outside and inside of the notched frequency range are vital characteristics of the UWB band-notched antennas. Variations of the group delay of designed antenna with and without slot are shown in Fig. 6. Favorably, the group delays outside and inside of the notched frequency band are about 0.2 and 1 ns, respectively. High variation of group delay inside the notched frequency band increases the signal distortion in this frequency range, which in turn improves the reduction of interference from other systems.

3. DOUBLE SLOT CONICAL MONOPOLE ANTENNA

In order to increase the value and uniformity of reflection coefficient in the notch frequency band and subsequently, decline the interference between the UWB and other systems, another slot has been added to the antenna as shown in Fig. 7. Therefore, the second slot eliminates purposely the same portion of the antenna frequency band as that removed by the first slot. Design parameters for the case of

Table 2. Dimensions of the proposed double slot conical antenna.

Symbol	Description	Length
H	Antenna length	25 mm
D_U	Upper diameter	20 mm
D_L	Lower diameter	1.3 mm
d	Distance from the ground	0.25 mm
L_0	Slant length of antenna	30 mm
R_g	Ground radius	50 mm
L_1	First Slot Length	15 mm
H_1	First Slot opening	2 mm
L_2	Second Slot Length	15 mm
H_2	Second Slot opening	1 mm

two slots are also shown in Fig. 7. Regarding to the second slot, the slot length is denoted by L_2. As discussed above, in order to increase the reflection coefficient in the notch frequency band, the rejection frequency band of both slots should be the same and from 5 GHz to 6 GHz. Moreover, to achieve a uniform and constant reflection coefficient in notched frequency band, the rejected frequency by the second slot should be accrued at 6 GHz. Hence, the length of the second slot will be quarter-wave length of determined rejection frequency of 6 GHz, ($L'_s \simeq \frac{\lambda_c}{4}$). In order to notch frequency ranges of the IEEE 802.11a and HIPERLAN/2 in this antenna with high and uniform reflection coefficient value, the appropriate values for L_s and L'_s are 15 mm and 12.5 mm respectively. Suitable parameters for double slot antenna are determined in Table 2.

The simulated current distributions on the antenna surface at 4 GHz, 5 GHz and 7 GHz are shown in Fig. 8. In Figs. 8(a) and (b), current distribution of antenna is uniform as well as surface current of conical antenna without slot. So slots play minimal role in current distribution at 4 and 7 GHz. At 5 GHz, the frequency of maximum reflection coefficient in the notched band, maximum and minimum current densities occur at the inner and outer ends of the antenna slots, respectively. It confirms that the slots act as resonator whose lengths are approximately quarter of the wavelength at the center frequency of the notched band. Direction of current in slots are perpendicular to that of antenna's surface current, furthermore, current on top and bottom walls of the slots are in opposite direction. So at frequency that surface current of antenna is concentrated in the antenna slots the antenna radiation

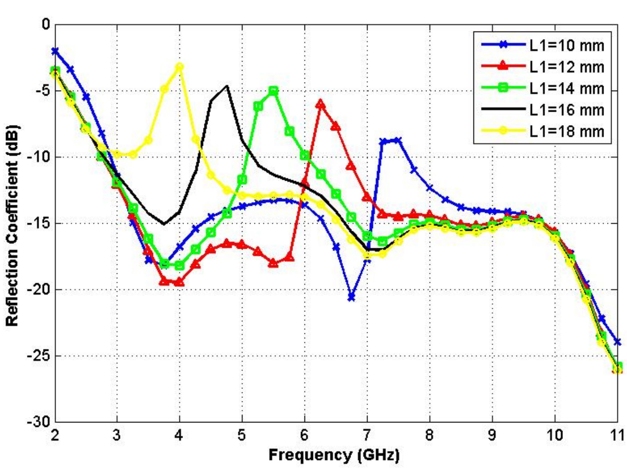


Figure 2. Simulated reflection coefficient with various slot length.

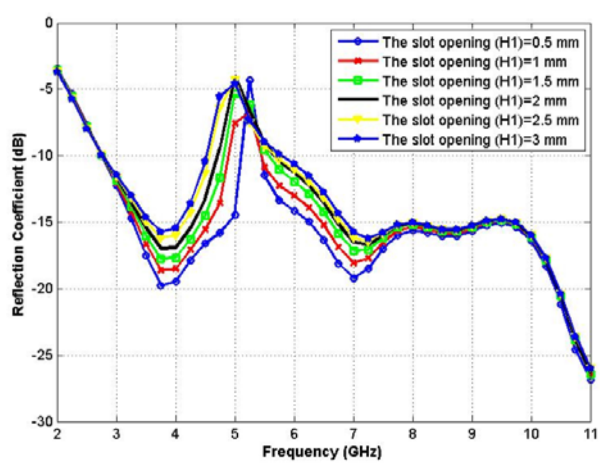


Figure 3. Simulated reflection coefficient with various slot opening.

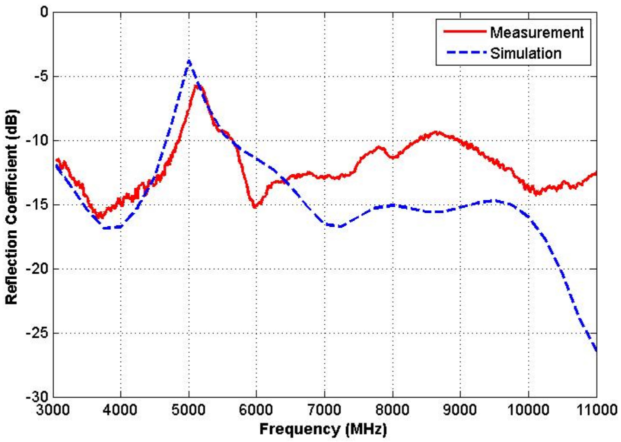


Figure 4. Measured and simulated reflection coefficient of the designed single slot antenna.

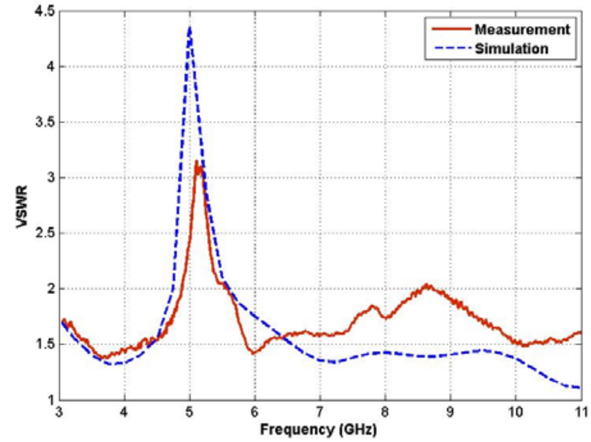


Figure 5. Measured and simulated VSWR of the designed single slot antenna.

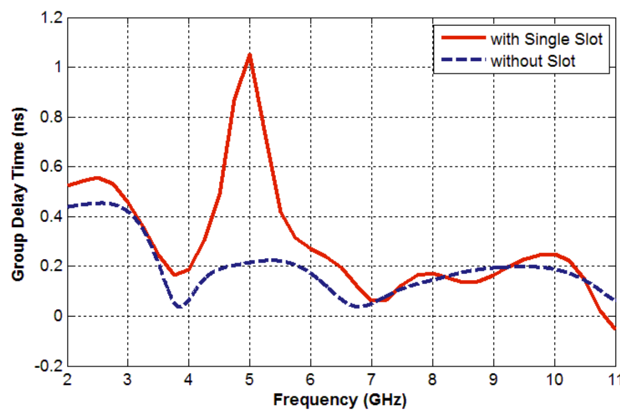


Figure 6. Simulated group delay of the designed single slot antenna.

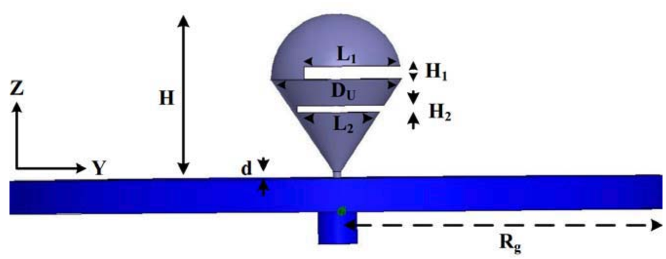


Figure 7. The proposed double slot antenna.

and subsequently its gain will be dropped drastically.

The reflection coefficient of the current antenna varies with several values of opening width for the second slot. According to simulation results, the maximum reflection coefficient occurs with 1 mm slot opening, so that the slot opening width in designed antenna is determined as 1 mm.

The proposed antenna based on obtained optimum values in Table 2 has been simulated by Ansoft HFSS software and manufactured as shown in Fig. 9.

The simulated and measured reflection coefficients are displayed in Fig. 10. The measurement and

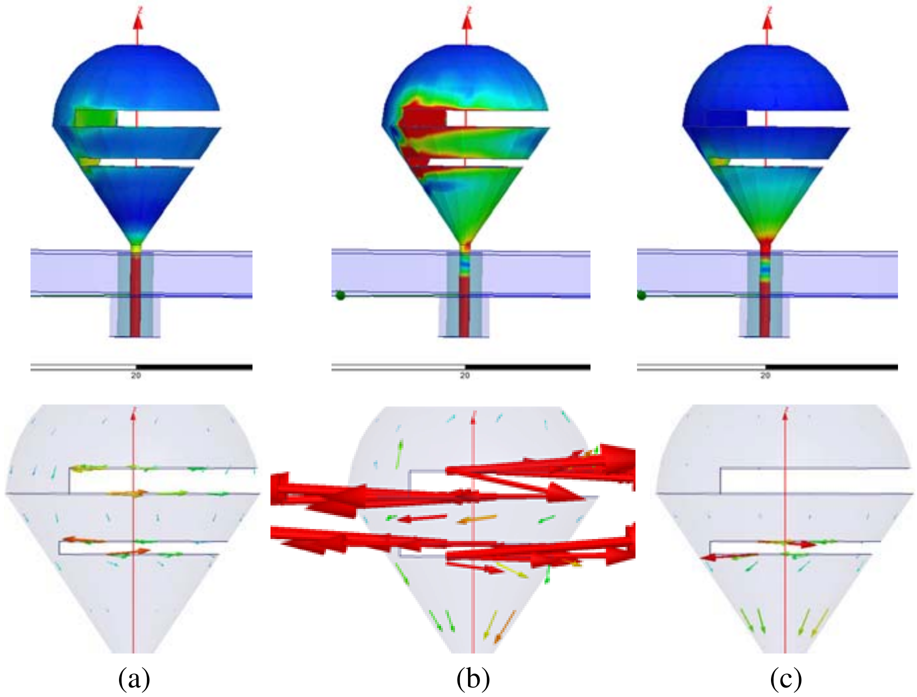


Figure 8. Simulated surface current on the proposed antenna, (a) 4 GHz, (b) 5 GHz, (c) 7 GHz.

Figure 9. Manufactured double slot antenna.

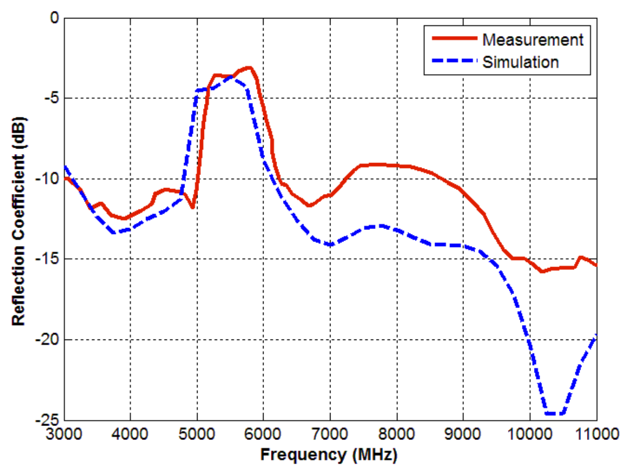


Figure 10. Measured and simulated reflection coefficient of double slot antenna.

simulation results are in good agreement with each other. It should be noted that the approximately constant difference between measurement and simulation results in high frequencies is due to low accuracy of fabrication in that range of frequencies. The reflection coefficient at the center frequency of notched band (5.5 GHz) is about −3 dB that is 2 dB higher than corresponding reflection coefficient for single slot antenna.

Thus, the rejection level at the notched frequency band is increased with proper application of additional slot. It should be noted that additional slot may also be designed to achieve multi-band antennas [24]. According to Fig. 10 reflection coefficient of the notched frequency band in double slot antenna is more uniform than single slot antenna. In this design additional slot is implemented for obtaining a rejected frequency bandwidth with uniform rejection in high value of reflection coefficient value. The simulated and measured VSWR of double slot antenna are displayed in Fig. 11.

Frequency variations of the group delay of the designed double slot conical antenna are illustrated in Fig. 12. The maximum group delay is 7.6 ns occurring at about 5 GHz, whereas the group delay for frequencies outside of notched band is about 0.2 ns. Extra slot increases group delay in notched frequency band in compare with single slot antenna. High and low group delays, respectively, inside and outside of the notched frequency band are significant characteristics of band-reject UWB antennas. High variation of group delay inside of the notch frequency band indicates high signal distortion in the radiated signal from the antenna.

Measured and simulated E and H-plane radiation patterns of the designed antenna at frequencies 4 and 12 GHz are shown in Fig. 13. There is a good agreement between the measured and simulated radiation pattern of the antenna. Similar to all other conical antennas, the E-plane of radiation pattern tilts away from the broadside. Fig. 13 illustrates that the H-plane of the radiation pattern is symmetrical in all operating frequencies of the antenna. In contrast, in the planar band-reject antennas, the H-plane of radiation pattern is not completely symmetrical and also widely fluctuates as the frequency

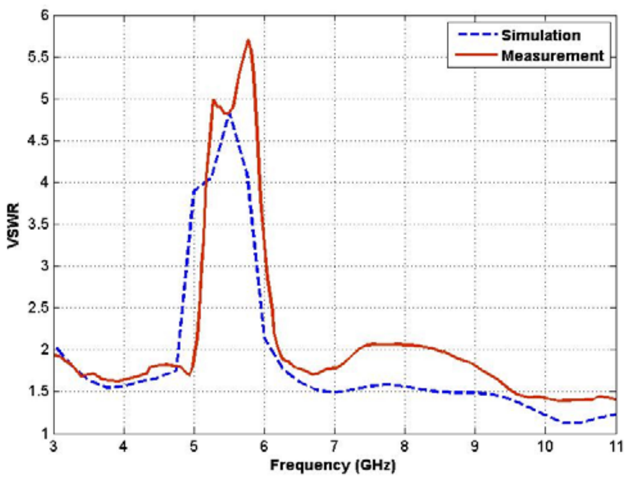


Figure 11. Measured and simulated VSWR of double slot antenna.

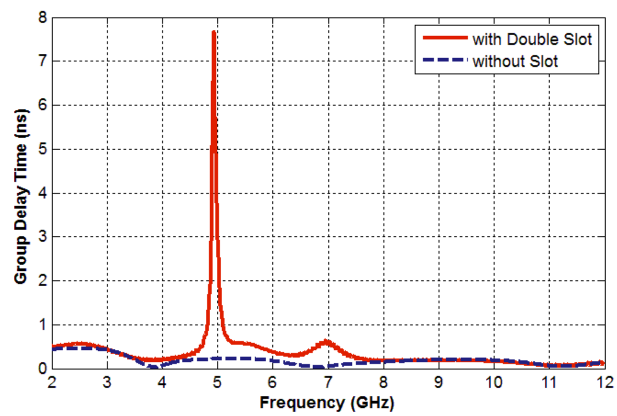
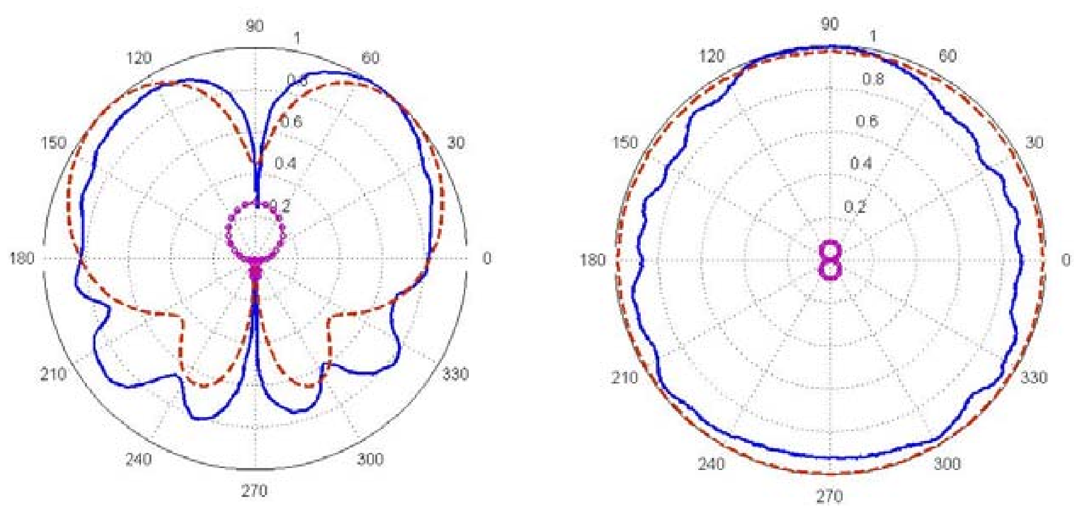


Figure 12. Simulated group delay time of the antenna with double and without slot.



E-plane *H*-plane

(a)

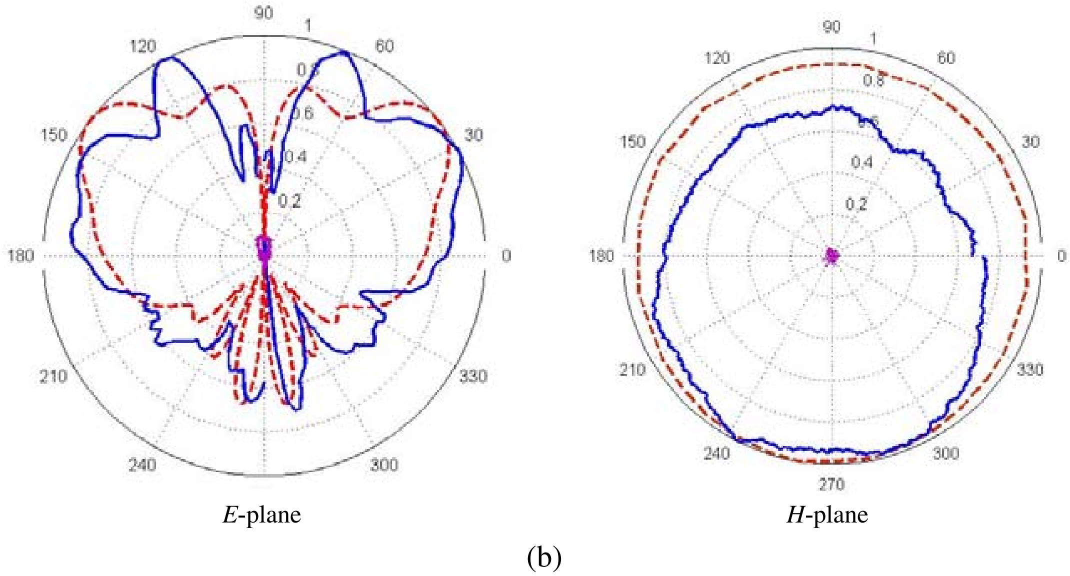


Figure 13. Measured (solid line), simulated (dashed line) co-polarization and cross-polarization (solid line with circle) radiation pattern in (a) 4, (b) 12 GHz.

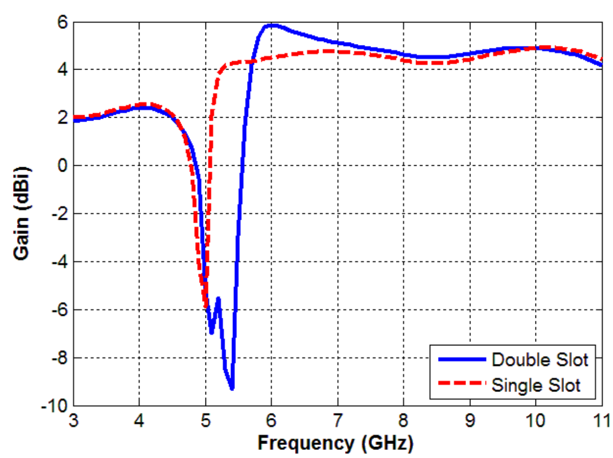


Figure 14. Gain variation versus frequency in double and single slot antenna.

increases. This is in fact a drawback for the use of planar antennas in the UWB systems, as was mentioned before. In addition, Low cross-polarization radiation pattern is a significant parameter of UWB antennas which improves their performance. As illustrated in Fig. 13, cross-polarization radiation pattern of the proposed antenna is very smaller than co-polarization radiation pattern. This specification is obtained by using of a large circle ground plate. The Large ground plate is effective to diminish of cross-polarization radiation pattern. Moreover, the path of return current is equal in the circle ground plate, so it contributes to more reduction in cross-polarization radiation pattern [20]. Due to symmetrical and stable H-plane radiation patterns with very small cross-polarization in a wide frequency band, the proposed antenna is a decent candidate for the use in UWB communication systems.

The gain variation of the designed antenna is shown in Fig. 14. It represents that the gain of proposed antenna drastically falls in the notched frequency band, so that the gain of the antenna in rejection frequency is approximately 14 dB lesser than other frequencies. Hence, the designed antenna well rejects the IEEE 802.11 and HYPERLAN signals and strongly reduces their interference in the UWB system performance.

4. CONCLUSION

In this paper, a novel single slot band-reject UWB antenna is proposed and manufactured to eliminate IEEE 802.11 and HIPERLAN interference in UWB system performance. Measurement results show that the reflection coefficient is less than −10 dB in frequency range from 3 to 4.9 GHz and from 5.8 to 11 GHz. This antenna rejects 4.9–5.8 GHz frequency band with −5 dB reflection coefficient. To increase and uniform the rejection of common frequency bandwidth in UWB and other communication systems, double slot antenna is proposed. Simulated and measured results show that the reflection coefficient of antenna is nearly uniform and about −3 dB in the notched frequency band from 4.9 to 6.2 GHz, whereas it is comparatively much lower at other frequencies. In contrast with planar antennas, measured H-plane radiation patterns of the proposed antenna are completely symmetric and stable in all operating frequencies. Therefore, the proposed antenna is preferred to the existing planar antennas. Moreover, notched frequency band in designed antenna is tunable by varying the position and length of the slots. The high capability of power handling of the proposed antenna as well as the mentioned favorable characteristics makes this antenna an appropriate candidate for communication systems.

REFERENCES

1. Federal Communications Commission, "1st report and order on ultra-wideband technology," Feb. 2002.
2. Kerkhoff, A. and H. Ling, "Design of a planar monopole antenna for use with ultra-wideband (UWB) having a band-notched characteristic," *Proc. IEEE Antennas and Propag. Soc. Int. Symp.*, 830–833, Columbus, OH, Jun. 2003.
3. Jun Cho, Y., K. H. Kim, D. H. Choi, S. S. Lee, and S. O. Park, "A miniature UWB planar monopole antenna with 5-GHz band-rejection filter and the time-domain characteristics," *IEEE Trans. on Antennas and Propagat.*, Vol. 54, No. 5, 1453–1460, May 2006.
4. Huang, C. Y. and W. C. Hsia, "Planar ultra-wideband antenna with a frequency notch characteristic," *Microw. Opt. Tech. Lett.*, Vol. 49, No. 2, 316–320, Feb. 2007.
5. Yoon, H., H. Kim, K. Chang, Y. J. Yoon, and Y. H. Kim, "A study on the UWB antenna with band-rejection characteristics," *Proc. IEEE Antennas and Propag. Soc. Int. Symp.*, Vol. 2, 1784–1787, Jun. 2004.
6. Karmakar, A., R. Ghatak, U. Banerjee, and D. R. Poddar, "An UWB antenna using modified Hilbert curve slot for dual band notch characteristics," *Journal of Electromagnetic Waves and Applications*, Vol. 27, No. 13, 1620–1631, 2013.
7. Gorai, A., A. Karmakar, M. Pal, and R. Ghatak, "Multiple fractal-shaped slots-based UWB antenna with triple-band notch functionality," *Journal of Electromagnetic Waves and Applications*, Vol. 27, No. 18, 2407–2415, 2013.
8. Biswas, B., R. Ghatak, A. Karmakar, and D. R. Poddar, "Dual band notched UWB monopole antenna using embedded omega slot and fractal shaped ground plane," *Progress In Electromagnetics Research C*, Vol. 53, 177–186, 2014.
9. Gao, Y., B. L. Ooi, and A. P. Popov, "Band-notched ultra wideband ring monopole antenna," *Microw. Opt. Tech. Lett.*, Vol. 48, No. 1, 125–126, Jan. 2006.
10. Kim, K. H., Y. J. Cho, S. H. Hwang, and S. O. Park, "Band-notched UWB planar monopole antenna with two parasitic patches," *Electronics Letters*, Vol. 41, No. 14, 783–786, Jul. 2005.
11. Thomas, K. G. and M. Sreenivasan, "A simple ultra wideband planar rectangular printed antenna with band dispensation," *IEEE Trans. on Antennas and Propagat.*, Vol. 58, No. 1, 27–34, Jan. 2010.
12. Wu, S. J., C. H. Kang, K. H. Chen, and J. H. Tarng, "Study of an ultera wideband monopole antenna with a band-notched open-looped resonator," *IEEE Trans. on Antennas and Propagat.*, Vol. 58, No. 6, 1890–1897, Jun. 2010.
13. Lee, W. S., D. Z. Kim, K. J. Kim, and J. W. Yu, "Wideband planar monopole antennas with dual band-notched characteristics," *IEEE Trans. on Microwave Theory and Techniques*, Vol. 54, No. 6, 2800–2806, Jun. 2006.

14. Peng, L. and C. L. Ruan, "UWB band-notched monopole antenna design using electromagnetic-bandgap structures," *IEEE Trans. on Microwave Theory and Techniques*, Vol. 59, No. 4, 1074–1081, Apr. 2011.
15. Daviu, E. A., M. C. Fabres, M. F. Bataller, and V. M. R. Penarrocha, "Modal analysis and design of band-notched UWB planar monopole antennas," *IEEE Trans. on Antennas and Propagat.*, Vol. 58, No. 5, 1457–1467, May 2010.
16. Wu, W. and Y. P. Zhang, "Analysis of ultra-wideband printed planar quasi-monopole antennas using the theory of characteristic modes," *IEEE Antennas and Propagat. Magazine*, Vol. 52, No. 6, 67–77, Dec. 2010.
17. Wang, H., H. Zhang, X. Liu, and K. Huang, "A CPW-fed ultra-wideband planar inverted cone antenna," *Progress In Electromagnetics Research C*, Vol. 12, 101–112, 2010.
18. Thwin, S. S., "Compact band-notched UWB printed planar inverted cone antennas," *International Journal of Computer Theory and Engineering*, Vol. 3, No. 6, Dec. 2011.
19. Hu, Z. H., P. S. Hall, J. R. Kelly, and P. Gardner, "Wideband conical monopole antenna with frequency band-notched behavior," *Electronics Letters*, Vol. 46, No. 23, 1542–1543, Nov. 2010.
20. Hu, Z. H., J. R. Kelly, P. S. Hall, and P. Gardner, "Wideband conical monopole antenna with integrated stop-band filter," *Progress In Electromagnetics Research C*, Vol. 27, 223–238, 2012.
21. Stutzman, W. L. and G. A. Thiele, "Broadband antennas," *Antenna Theory and Design*, 2nd Edition, 243–246, John Wiley and Sons, Inc., New York, 1998.
22. Rahmati, B. and H. R. Hassani, "Multi-notch slot loaded wide band planar plate monopole antenna," *IEEE Trans. on Antennas and Propagat.*, Vol. 4, No. 12, 2160–2165, 2010.
23. Ansoft HFSS Ansys Corporation, 2010, [Online], available: www.ansoft.com.
24. Foudazi, A. and H. Hassani, "Small UWB planar monopole antenna with added GPS/GSM/WLAN bands," *IEEE Trans. on Antennas and Propagat.*, Vol. 60, No. 6, 2987–2992, Jun. 2012.